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(54) Title: METHOD FOR REDUCING SAG IN DRILLING, COMPLETION AND WORKOVER FLUIDS

(57) Abstract: A method is disclosed for reducing sag in drilling and completion fluids and in workover fluids. The method employs a drilling fluid comprising a low molecular weight polyalkyl methacrylate with an average molecular weight ranging from about 40,000 to about 90,000. This additive does not result in enhanced viscosity of the fluid.

METHOD FOR REDUCING SAG IN DRILLING, COMPLETION AND WORKOVER FLUIDS

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to methods and compositions for reducing the sag of a weight material in a drilling fluid for drilling operations such as drilling, running casing, and cementing and in fluids for workover operations.

2. Description of Relevant Art

A drilling fluid, or "mud" which a drilling fluid is also often called, is a specially designed fluid that is circulated in a wellbore or borehole as the wellbore is being drilled in a subterranean formation to facilitate the drilling operation. As used herein, the term "drilling operation" shall mean drilling, running casing and/or cementing unless indicated otherwise. The various functions of a drilling fluid include removing drill cuttings from the wellbore, cooling and lubricating the drill bit, aiding in support of the drill pipe and drill bit, and providing a hydrostatic head to maintain the integrity of the wellbore walls and prevent well blowouts. Specific drilling fluid systems are selected to optimize a drilling operation in accordance with the characteristics of a particular geological formation.

A drilling fluid typically comprises water and/or oil or synthetic oil or other synthetic material or synthetic fluid as a base fluid, with solids in suspension. A non-aqueous based drilling fluid typically contains oil or synthetic fluid as a continuous phase and may also contain water dispersed in the continuous phase by emulsification so that there is no distinct layer of water in the fluid. Such dispersed water in oil is generally referred to as an invert emulsion or water-in-oil emulsion.

A number of additives may be included in such drilling fluids and invert emulsions to enhance certain properties of the fluid. Such additives may include, for example, emulsifiers, weighting agents, fluid-loss additives or fluid-loss control agents, viscosifiers or viscosity control agents, and alkali. Weighting agents are commonly added to increase the density of the fluid. Barite or barytes (barium suphates) are typical weighting agents, although other minerals are also common.

Viscosifiers are typically added to increase the viscosity of the fluid to facilitate or enhance suspension of weighting agents in the fluid. Organoclays, such as for example

bentonites hectorites and other swelling clays, chemically treated to enhance their oil wettability, are typical viscosifiers. Organic polymers and long chain fatty acids may also be added to increase viscosity and aid weighting agent suspension.

Generally, increased viscosity leads to improved suspension of weighting agents which in turn limits or reduces problematic "sag." However, excessive viscosity can have adverse effects on equivalent circulating density (causing it to increase), which can also lead to problems, particularly in wells where the differences in subterranean formation pore pressures and fracture gradients are small, as commonly encountered in deep water wells.

Under certain well conditions, including without limitation, well geometries, temperatures and pressures, a phenomenon called "barite sag" or "sag" can occur. "Sag" is generally a "significant" variation in mud density (> 0.5 lbm/gal) along the mud column, which is the result of settling of the weighting agent or weight material and other solids in the drilling fluid. Sag generally results from the inability of the drilling fluid under the particular well conditions to provide adequate suspension properties.

Suspensions of solids in non-vertical columns are known to settle faster than suspensions in vertical ones. This effect is driven by gravity and impeded by fluid rheology, particularly non-Newtonian and time dependent rheology. Manifestation of this effect in a drilling fluid is also known as "sag," although sag occurs in both vertical and non-vertical wells.

Drilling fluids in deviated wellbores can exhibit sag in both static and dynamic situations. In this context, static is a totally quiescent fluid state, such as when drilling has ceased; dynamic is any situation where the fluid is exposed to a shear stress, such as for example during drilling. As used hereinafter, the term "sag" shall be understood to include both static and dynamic sag unless specifically indicated otherwise.

Sag can result in formation of a bed of the weighting agents on the low side of the wellbore, and stuck pipe, among other things. In some cases, sag can be very problematic to the drilling operation and in extreme cases may cause hole abandonment. As directional drilling and deviated wellbores become more common if not the norm in the oil and gas industry, more and improved methods are needed to reduce or eliminate sag, without adding viscosity problems.

SUMMARY OF THE INVENTION

The present invention provides a method for reducing sag or the settlement of weighting agents in an oil based or invert emulsion drilling fluid without significantly increasing the viscosity of the drilling fluid. The method comprises adding a low molecular weight polyalkyl methacrylate to the drilling fluid. No copolymer such as vinyl pyrrolidone or its equivalent is needed or used. The invention also provides a drilling fluid comprising the additive. As used herein, the term "drilling fluid" shall be understood to include fluids used in drilling, cementing, casing, workover and/or other similar downhole operations.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

In the present invention, an oil or invert emulsion based drilling fluid comprising a low molecular weight polyalkyl methacrylate additive is used in drilling operations or workover operations. The fluid provides good suspension of weighting agents without excessive viscosity and shows a reduced rate of sag when compared to prior art fluids.

The effective average molecular weight range of the polyalkyl methacrylate is about 40,000 to about 90,000. A polyalkyl methacrylate within this weight range is commercially available under the tradename VISCOPLEX® 1-304, available from ROHMAX or Rohm GmbH of Germany. Preferred concentrations of this additive in the drilling fluid are in the range of about 0.5 ppb to about 10 ppb. At these concentrations, this additive of the present invention does not significantly increase the viscosity of the drilling fluid when measured at either about 120 degrees Fahrenheit and ambient pressure or at temperatures up to about 400 degrees Fahrenheit and 20,000 psig pressure.

Sag factors achieved using this low molecular weight polyalky methacrylate additive range from about 0.50 to about 0.51. Typical prior art drilling fluids presently in use in the oil and gas industry exhibit sag factors ranging from about 0.51 to about 0.55, where a sag factor of 0.50 indicates no settlement of weighting agent (i.e., no sag). Copolymers with the polyalkyl methacrylate are not needed in the present invention.

United States Patent No. 6,204,224, issued March 20, 2001 to Quintero et al. previously reported use of a copolymer of a high molecular weight polyalkyl methacrylate and vinyl pyrrolidone for rheological modification and filtration control for oil or invert emulsion based, and particularly ester and synthetic based, drilling fluids. These copolymers

are said to be capable of building a viscoelastic rheological structure which serves to prevent or reduce barite sag and provide cuttings transport. The patent includes data comparing the copolymer of high molecular weight polyalkyl methacrylate and vinyl pyrrolidone with a copolymer of low molecular weight polyalkyl methacrylate and vinyl pyrrolidone which indicates that the latter yielded poor results in contrast to the claimed high molecular weight polyalkyl methacrylate and vinyl pyrrolidone copolymer. The data in the patent followed traditional expectations that the more viscous fluid would provide the better suspension properties and be less likely to sag. Addition of the high molecular weight polyalkyl methacrylate and vinyl pyrrolidone copolymer to the drilling fluid significantly increased the viscosity of the fluid, which resulted in the drilling fluid being a highly viscous fluid.

Notwithstanding the teaching of U.S. Patent No. 6,204,224 to Quintero, et al., the present invention departs from traditional thinking and unexpectedly provides a formulation that yields superior results in reducing sag without added viscosity and thus without consequent problems that highly viscous fluids can cause. The advantages of the present invention are demonstrated by the test data below.

EXPERIMENTS

Initially, samples of field drilling mud were either static aged or hot rolled at 400 degrees Fahrenheit to evaluate the mud at 50 degrees Fahrenheit higher than the mud was originally engineered to withstand. The mud generally held up well, although the difference between the top and bottom density results were excessive. To improve barite (weighting agent) suspension, two different products were added to samples (one product per sample) for comparison in concentrations of 1.0 lb/bb. These two products were castor oil and VISCOPLEX® 1-304. Data from this experiment is shown in Table 1 below.

TABLE 1

Field Mud Sample	bbl		1.0	1.0	1.0
Hydrogenated Castor Oil	lb		---	1.0	---
VISCOPLEX®1-304	lb		---	---	1.0
Static Aged @ 400 °F	**hour**		**16**	**16**	**16**
Plastic Viscosity	cP	58	75	80	74
Yield Point	$lb/100ft^2$	22	29	23	27
10 second Gel	$lb/100ft^2$	14	24	20	24
10 minute Gel	$lb/100ft^2$	19	40	38	37
Fann 35 dial readings @ 120°F					
Θ 600		138	179	183	175
Θ 300		80	104	103	101
Θ 200		60	77	76	74
Θ 100		38	48	46	48
Θ 6		13	16	14	16
Θ 3		10	14	12	14
Weight	lb/gal		18.0	18.0	18.0
Top Oil Separation	%		3.0	3.0	2.5
Gelled/Settling	y/n		y/n	y/n	y/n
Top Stratification	sg		1.87	2.05	2.10
Middle Stratification	sg		2.10	2.21	2.17
Bottom Stratification	sg		2.29	2.32	2.22

The concentration of each additive--the castor oil and the VISCOPLEX® 1-304—was increased in additional samples of field mud to 2.0 lb/bbl. As the data in Table 2 indicates, this addition had the desired effect of reducing settlement (e.g., sag) during static aging without adverse effects on (i.e., without increasing) either viscosity or fluid loss. Of these two additives, the better results were seen with VISCOPLEX® 1-304 and so the remaining studies were conducted only with VISCOPLEX® 1-304.

TABLE 2

Field Mud Sample	bbl		1.0	1.0	1.0
Hydrogenated Castor Wax	lb		---	2.0	---
VISCOPLEX®1-304	lb		---	---	2.0
Static Aged @ 400 °F	**hour**		**16**	**16**	**16**
Plastic Viscosity	cP	54	60	75	62
Yield Point	lb/100ft²	22	27	35	28
10 second Gel	lb/100ft²	13	17	21	20
10 minute Gel	lb/100ft²	18	42	49	44
Electrical Stability	volt	---	654	776	878
HTHP Fluid Loss @ 400°F	ml/30min	---	---	2.2	2.0
Fann 35 dial readings @ 120°F					
Θ 600		130	147	185	152
Θ 300		76	87	110	90
Θ 200		57	65	83	69
Θ 100		36	42	53	46
Θ 6		12	14	17	17
Θ 3		10	12	15	14
Weight	lb/gal		18.0	18.0	18.0
Top Oil Separation	%		2.5	2.5	1.5
Gelled/Settling	y/n		y/n	y/n	y/n
Top Stratification	sg		1.94	2.01	2.12
Middle Stratification	sg		2.12	2.16	2.19
Bottom Stratification	sg		2.29	2.29	2.24

Laboratory samples of a drilling mud approximately like the field mud were prepared Different concentrations of VISCOPLEX® 1-304 was added to the samples—1.0 lb/bbl concentration in one sample and 2.0 lb/bbl concentration in another sample. These samples were static aged at 400 degrees Fahrenheit for 16 hours. The treated laboratory samples showed low density variations and minimal top oil separation, with the 2.0 lb/bbl concentration giving slightly better results. The data from this experiment is shown in Table 3 below. The products in the tables designated by tradenames EZ MUL® NT, INVERMUL® NT, DURATONE®, BENTONE®, and SUSPENTONE™ are available from Halliburton Energy Services, Inc. in Houston, Texas, U.S.A. These products are common additives for

completing a drilling fluid and comprise emulsifiers, rheological control additives, suspension agents and the like.

TABLE 3

MUD SAMPLE COMPOSITION					
Total DF 1 (invert emulsion base) bbl		0.393		0.393	0.393
EZ MUL® NT ppb		15.0		15.0	15.0
INVERMUL® NT ppb		3.0		3.0	3.0
DURATONE® HT ppb		20.0		20.0	20.0
Lime ppb		10.0		10.0	10.0
BENTONE® 38 ppb		2.0		2.0	2.0
Water bbl		0.102		0.102	0.102
$CaCl_2$ ppb		19.01		19.01	19.01
SUSPENTONE™ ppb		2.0		2.0	2.0
Barite ppb		559.93		559.9	559.93
RM™ 63 ppb		1.0		1.0	1.0
VISCOPLEX® 1-304 ppb		---		1.0	2.0
Static Aged @ 400°F hour		**16**		**16**	**16**
MUD SAMPLE PROPERTIES					
Plastic Viscosity cP	65	62	60	62	61
Yield Point $lb/100ft^2$	25	19	23	16	17
10 second Gel $lb/100ft^2$	15	12	15	10	14
10 minute Gel $lb/100ft^2$	26	31	20	30	32
Fann 35 dial readings @ 120°F					
Θ 600	155	143	143	140	139
Θ 300	90	81	83	78	78
Θ 200	68	59	62	57	57
Θ 100	44	36	38	34	35
Θ 6	15	10	12	8	9
Θ 3	13	9	10	7	7
Weight lb/gal		18.0		18.0	18.0
Top Oil Separation %		3.5		2.5	2.0
Gelled/Settling y/n		y/n		y/n	y/n
Top Stratification sg		2.11		2.16	2.15
Middle Stratification sg		2.22		2.18	2.17
Bottom Stratification sg		2.36		2.22	2.20

One sample of the laboratory mud without the VISCOPLEX® 1-304 additive and one sample of the laboratory mud with 2.0 lb/bbl VISCOPLEX® 1-304 were placed in hot roll cells and left static in an oven for 96 hours at 400 degrees Fahrenheit. Though there was top oil separation and settlement in both cells, the sample with the VISCOPLEX® 1-304 showed significantly better results, as can be seen in Table 4.

TABLE 4

MUD SAMPLE COMPOSITION:				
Total DF 1 (invert emulsion base)	bbl		0.393	0.393
EZ MUL® NT	ppb		15.0	15.0
INVERMUL® NT	ppb		3.0	3.0
DURATONE® HT	ppb		20.0	20.0
Lime	ppb		10.0	10.0
Bentone 38	ppb		2.0	2.0
Water	bbl		0.102	0.102
$CaCl_2$	ppb		19.01	19.01
SUSPENTONE	ppb		2.0	2.0
Barite	ppb		559.93	559.93
RM 63	ppb		1.0	1.0
VISCOPLEX® 1-304	ppb		---	2.0
Static Aged @ 400°F	**hour**		96	96
MUD SAMPLE PROPERTIES				
Plastic Viscosity	cP	60	63	65
Yield Point	$lb/100ft^2$	23	13	15
10 second Gel	$lb/100ft^2$	15	13	15
10 minute Gel	$lb/100ft^2$	20	32	35
Electrical Stability	volt	---	799	833
Fann 35 dial readings @ 120°F				
Θ 600		143	139	145
Θ 300		83	76	80
Θ 200		62	54	57
Θ 100		38	30	34
Θ 6		12	7	8
Θ 3		10	5	7
Weight	lb/gal		18.0	18.0
Top Oil Separation	%		20.0	15.0
Gelled/Settling	y/n		y/n	y/n

Top Stratification	sg		1.84	2.0
Middle Stratification	sg		2.36	2.20
Bottom Stratification	sg		2.70	2.50

A sample of the field mud sample without VISCOPLEX® and a sample of the field mud sample with 2.0 lb/bbl VISCOPLEX® 1-304 were sheared on a Silverson mixer over a 60 minute period before being static aged at 400 degrees Fahrenheit for 16 hours. The results, shown in Table 5, indicated no significant difference between the two samples, which indicated that VISCOPLEX™ can withstand shear.

TABLE 5

Field Mud Sample			
Sheared for 1 hour	bbl	1.0	---
VISCOPLEX®1-304	ppb	---	2.0
Static Aged @ 400°F	**hour**	**16**	**16**
Plastic Viscosity	cP	70	70
Yield Point	$lb/100ft^2$	27	28
10 second Gel	$lb/100ft^2$	22	26
10 minute Gel	$lb/100ft^2$	39	41
Electrical Stability	volt	838	1013
Fann 35 dial readings @ 120°F			
Θ 600		167	168
Θ 300		97	98
Θ 200		72	73
Θ 100		44	47
Θ 6		14	17
Θ 3		12	15
Weight	lb/gal	18.0	18.0
Top Oil Separation	%	3.5	2.5
Gelled/Settling	y/n	y/n	y/n
Top Stratification	sg	2.10	2.12
Middle Stratification	sg	2.18	2.14
Bottom Stratification	sg	2.22	2.17

Fann 70 rheological profiles were carried out on samples of both field mud without VISOPLEX® 1-304 and field mud with 2.0 lb/bbl VISCOPLEX® 1-304. After the samples

reached the maximum temperatures and pressures desired, the samples were left for 4.5 hours at these maximum temperatures and pressures before instrument readings were re-taken. In addition to the Fann 70, the viscosity of both samples was measured on a Fann 35 at 5 degrees Centigrade to simulate cold climates. These tests showed no detrimental effects from the addition of VISCOPLEX® 1-304. The test data is reported in Tables 6 and 7 below.

TABLE 6
FANN 70 RHEOLOGICAL PROFILE
Field Mud Sample

Temperature (°C):	50	100	150	204	204	-5
Pressure (psi):	0	5000	11000	17500	17500	Fann 35
					4.5 Hours	
600 rpm	132	107	102	118	103	O/S
300 rpm	75	64	61	72	53	O/S
200 rpm	57	50	48	55	37	249
100 rpm	38	36	34	37	21	148
60 rpm	28	28	27	28	16	---
30 rpm	22	22	22	22	10	---
6	13	15	15	13	5	35
3	11	13	13	10	3	29
Plastic Viscosity, cp	57	43	41	46	50	---
Yield Point, lb/100ft^2	18	21	20	26	3	---
Gel, 10 sec. lb/100ft	12	13	13	10	3	37
Gel, 10 min. lb/100ft	15	16	15	13	6	61

TABLE 7
FANN 70 RHEOLOGICAL PROFILE
Field Mud Sample + 2lb/bbl VISCOPLEX® 1-304

Temperature (°C):	50	100	150	204	204	-5
Pressure (psi):	0	5000	11000	17500	17500	Fann 35
					4.5 Hours	
600 rpm	144	123	96	99	97	O/S
300 rpm	84	79	63	60	52	O/S
200 rpm	65	64	52	47	39	253
100 rpm	44	47	39	34	23	152
60 rpm	34	39	32	25	17	---
30 rpm	25	31	26	21	11	---
6	16	22	19	14	6	36
3	14	21	17	11	3	30
Plastic Viscosity, cp	60	44	33	29	45	---
Yield Point, lb/100ft^2	24	35	30	31	7	---
Gel, 10 sec. lb/100ft	14	21	17	11	3	37
Gel, 10 min. lb/100ft	16	23	19	14	6	63

Several apparatus and procedures are available for measuring sag. A typical example is stratification testing to determine or evaluate the "sag" performance of a drilling fluid, i.e., the fluid's tendency to "sag." The procedure used in stratification testing is as follows:

A sample of the fluid or formulation is sealed within a stainless steel cell and placed vertically in an oven maintained at the expected maximum temperature of the well. The cell is usually pressurized using nitrogen to prevent loss of volatiles from the fluid. After the test period, typically 16 hours, the cell is depressurized and the volume of "top" (i.e., separated) oil is measured and expressed as a percentage of the total fluid volume. After removal of the top oil, the density of the fluid is measured at three depths—top, middle, and bottom. A "sag factor" is calculated by dividing the bottom density by the sum of the top and bottom densities. A sag factor of 0.5 indicates no settlement of weighting agents.

Stratification data is reported for sag calculations in Tables 1-5 above. As previously noted, the sag factors for the fluid tested with VISCOPLEX® 1-304 ranged from about 0.50

to about 0.51, generally indicating that sag either did not occur or did not occur in an appreciable or significant amount.

The viscosity of drilling fluid is typically measured by use of concentric cylinder viscometers such as the Fann 35, available from Fann Instruments in Houston, Texas, U.S.A. The viscosity of fluids under downhole conditions, i.e., temperatures up to about 500 degrees Fahrenheit and pressures to 20,000 psig, is typically measured using an instrument such as the Fann 70, available from Fann Instruments in Houston, Texas, U.S.A. Viscosity data is reported in all of the tables above and comparison of the viscocities of the fluids with and without VISCOPLEX® 1-304 indicates that the addition of VISCOPLEX® 1-304 to the fluid did not appreciably or significantly alter the viscosity of the fluid.

These experiments indicate that a low molecular weight polyalkyl methacrylate may be added to oil or invert emulsion based drilling fluids to obtain improved suspension properties or reduced sag without altering the viscosity of the fluid. Further, this additive does not seem to significantly alter or increase the fluid loss experienced with use of the fluid and the additive provides a further benefit of improving the static age results seen with the fluid.

The foregoing description of the invention is intended to be a description of preferred embodiments. Various changes in the details of the described drilling fluid and method can be made without departing from the intended scope of this invention as defined by the appended claims.

We claim:

1. A method for reducing sag in an oil or invert emulsion based drilling fluid, said method comprising adding to said fluid a low molecular weight polyalkyl methacrylate.

2. The method of claim 1 wherein the polyalkyl methacrylate has an average molecular weight ranging from about 40,000 to about 90,000.

3. The method of claim 1 wherein said fluid has a sag factor in the range of about 0.50 to about 0.51.

4. The method of claim 3 wherein said sag factor is determined according to stratification testing.

5. The method of claim 1 wherein the viscosity of said fluid before and after said addition of polyalkyl methacrylate is substantially the same.

6. The method of claim 1 wherein said polyalkyl methacrylate is provided in said fluid in a concentration ranging from about 0.5 ppb to about 10 ppb.

7. The method of claim 6 wherein said concentration of polyalky methacrylate ranges from about 1 ppb to about 2 ppb.

8. The method of claim 1 wherein said drilling fluid is used in drilling or completion operations.

9. The method of claim 1 wherein said drilling fluid is used in workover operations.

10. A drilling fluid comprising an oil or invert emulsion base, weighting agents and a low molecular weight polyalkyl methacrylate.

11. The drilling fluid of claim 10 wherein said polyalkyl methacrylate has an average molecular weight ranging from about 40,000 to about 90,000.

12. The drilling fluid of claim 10 wherein said polyalkyl methacrylate has a sag factor in the range of about 0.50 to about 0.51.

13. The drilling fluid of claim 10 wherein polyalkyl methacrylate is provided in said fluid in a concentration ranging from about 0.5 ppb to about 10 ppb.The drilling fluid of claim 13 wherein said concentration of polyalky methacrylate ranges from about 1 ppb to about 2 ppb.

14. The drilling fluid of claim 10 further comprising emulsifiers.

15. The drilling fluid of claim 14 further comprising at least one additive selected from the group comprising rheological additives, fluid loss control additives, and suspension agents.

16. A method for improving the suspension properties of an oil or invert emulsion based drilling fluid without significantly increasing the viscosity of said fluid, said method comprising adding to said fluid an additive comprising a low molecular weight polyalky methacrylate.

17. The method of claim 16 wherein said polyalkyl methacrylate is provided in a concentration ranging from about 0.5 ppb to about 10 ppb.

18. The method of claim 16 wherein said polyalkyl methacrylate has an average molecular weight ranging from about 40,000 to about 90,000.

19. The method of claim 16 wherein said fluid is used in drilling operations, completion operations, or workover operations in a borehole penetrating a subterranean formation.

INTERNATIONAL SEARCH REPORT

PCT/GB2004/001950

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 C09K7/06

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 C09K

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, PAJ, COMPENDEX

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X,P	US 2004/002426 A1 (TEMPLE COLIN ET AL) 1 January 2004 (2004-01-01) the whole document -----	1-19
X	US 6 204 224 B1 (BRADFORD JR WILLIAM R ET AL) 20 March 2001 (2001-03-20) column 3 - column 4 examples 1-4 -----	1-19
X	GB 2 342 671 A (BAKER HUGHES INC) 19 April 2000 (2000-04-19) page 3 - page 5; examples 1-4 -----	1-19
A,P	US 6 586 372 B1 (BRADBURY ANDREW ET AL) 1 July 2003 (2003-07-01) the whole document -----	1-19
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[X] Further documents are listed in the continuation of box C. [X] Patent family members are listed in annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
25 August 2004	01/09/2004

Name and mailing address of the ISA	Authorized officer
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